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Numerical Analysis on Mechanics of Interaction Between Slurry and Soil in Earth Dam by Splitting Grouted

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Abstract

Based on the fluid-solid coupling by using the numerical analysis, the mechanics of interaction between slurry and soil in earth dam by splitting grouted are studied. Considering the seepage of slurry in the dam, the Mohr-Coulomb Hardening constitutive model is adopted in this paper through analyzing the pore pressure, stress and strain of the earth dam. It is founded that the slurry by splitting grouted is distributing as earth dam axis as the center and diffusing around. The stress of earth dam is improved by the quadratic stress regulation. Because of the interaction between slurry and soil, the horizontal displacement of earth dam by splitting grouted is generated. Those cause the cracks at the dam abutment.

Keywords: splitting grouted; numerical analysis; earth dam; pore pressure; stress-stain

1. Introduction

As an effective technique of anti-seepage and reinforcement, the splitting grouted in earth dam is promoted and applied in many domestic projects for anti-seepage and reinforcement of dangerous reservoirs. With this technique, a certain amount of grouting pressure is applied at the dam axis to control the split dam body at first; after that, an appropriate amount of seriflux is injected into the dam body to fill the holes and crannies in the dam body, and form an effective anti-seepage solid bodies, thus improving

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the stress state of dam body and achieving the consolidating the dam structure [1-3]. However, the mechanism of splitting grouted is containing many reasons [4]. The interaction between slurry and soil is one key reason. To investigate the mechanism of interaction between slurry and soil, based on the large-scale finite element software ABAQUS and fluid-solid coupling analysis, Mohr-Coulomb Hardening constitutive model is adopted. Through the fluid-solid coupling computation, the distribution law of pore pressure and stress-strain of dam are studied. Furthermore, the mechanism of interaction between slurry and soil is revealed.

2. Computational model and analysis method

As one of the large-scale general-purpose FEM packages, ABAQUS is capable of nonlinear computation and poses a user-friendly interface [5].

2.1. Mohr-Coulomb hardening model

The difference between this model and Mohr-Coulomb model lies in that when plastic yielding occurs to a certain region, various attributes, such as cohesive force, internal friction angle, dilation angle and tensile strength, are constant in Mohr-Coulomb model, while in the strain hardening model, hardening will occur. Its failure criterion and yielding function in the hardening model are identical to those in Mohr-Coulomb model. The two hardening parameters in the hardening model are the shear hardening parameter increment Δk^s and the stretch-draw hardening parameter increment Δk^t [6, 7] which are expressed below:

$$\Delta k^s = \frac{1}{\sqrt{2}}((\Delta\varepsilon_1^{ps} - \Delta\varepsilon_m^{ps})^2 + (\Delta\varepsilon_m^{ps})^2 + (\Delta\varepsilon_3^{ps} - \Delta\varepsilon_m^{ps})^2)^{\frac{1}{2}} \tag{1}$$

Where $\Delta\varepsilon_m^{ps} = \frac{1}{3}(\Delta\varepsilon_1^{ps} + \Delta\varepsilon_3^{ps})$ represents the plastic shear strain increment; $\Delta k^t = \left|\Delta\varepsilon_3^{pt}\right|$ represents the tensile hardening increment.

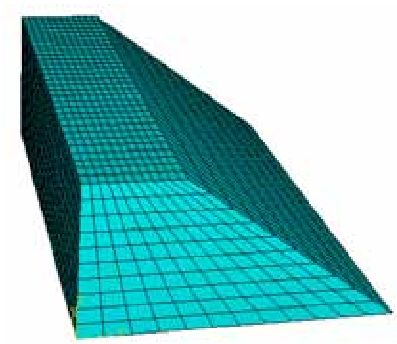
2.2. Finite element computational model and analysis method

By taking into account of the characteristics of the construction process of anti-seepage and reinforcement by splitting grouted as well as the features of seepage of grouting seriflux, the grouting axis is taken as the central axis, and one half of the dam body is selected as the research object. Based on the large-scale numerical calculation software ABAQUS, the finite element computational model for the three-dimensional semi-dam is built, as shown in Figure 1. In this model, the height of the dam body is 10.0m; the length of dam base is 20.0m; the length of dam top is 6.0m; the grout holes are located on the grouting axis. During the computation, the parameters of computational mechanics were adopted, as shown in Table 1.

Table 1. Parameters of computational mechanics for the dam body

Name of the mechanical parameter	Poros ity n	Permeability coefficient k/(cm/s)	Cohesive force c/(KPa)	Internal friction angle $\phi/°$	Elastic modulus E/(MPa)	Volume weight r/(t/m^3)
Grouting area	0.30	8.23×10^{-8}	40.00	25.00	20.00	2.00
Influence area of grouting	0.38	5.23×10^{-7}	34.50	23.00	18.00	1.92
Soil filling of earth dam	0.47	6.56×10^{-5}	28.80	21.00	16.00	1.80

3. Numerical results analysis



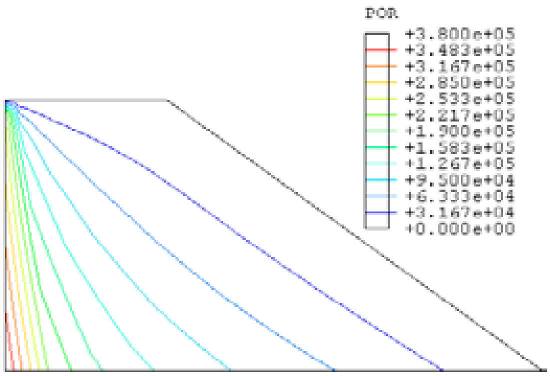
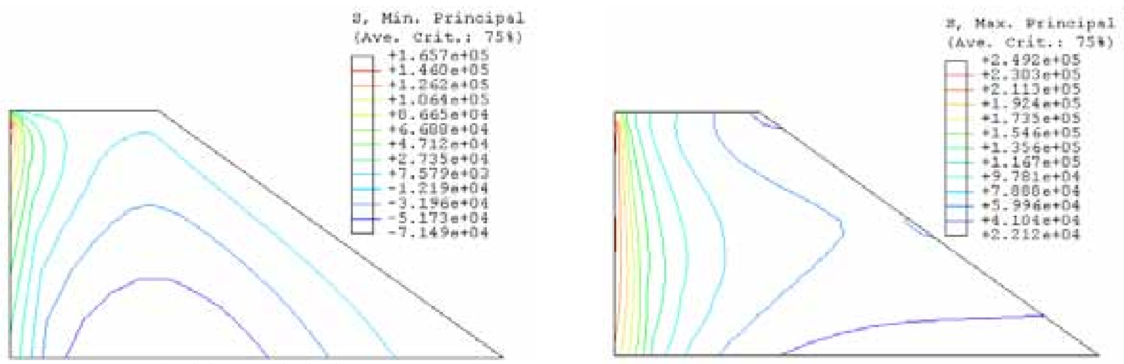


Fig.1. Mesh of embankment (left)
Fig.2. Contour map of pore pressure during splitting grouted for earth dam (right)

3.1. Pore pressure analysis

The distribution of pore pressure generated by slurry inside the dam body during splitting grouted is shown in Figure 2. It is observed that (1) the pore pressures generated by slurry are normal to the dam axis and are distributing as earth dam axis as the center and diffusing around. (2) The maximal value of pore pressure is located at the dam axis and bottom of dam. At the same time, the value of pore pressure is decreasing with the increase of distance to dam axis and height inside the dam body.

3.2. Stress analysis



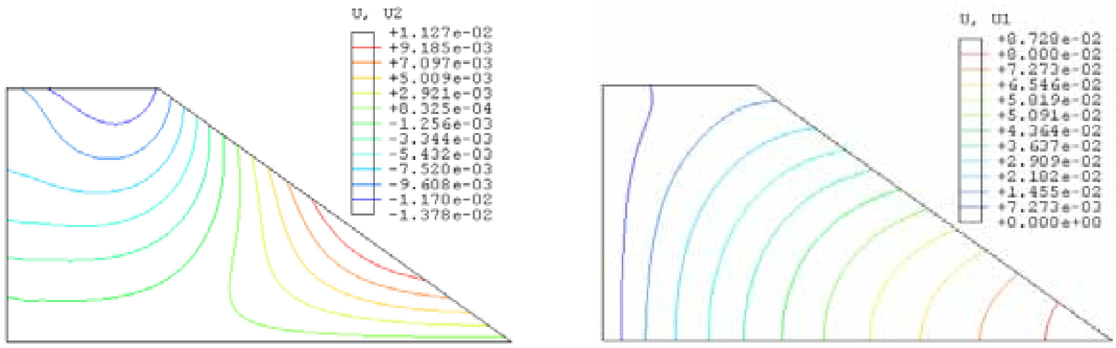
(a) minimum principal stress (b) maximum principal stress

Fig.3. Minimum and maximum principal stress of earth dam after splitting grouted

The distribution of the minimum and maximum principal stresses of the dam body after splitting grouting is shown in Figures 3. It is founded (1) as anti-seepage and reinforcement with splitting grouted proceeded, anti-seepage curtain core wall is formed inside the dam body after splitting grouted, and the stresses of the dam body are readjusted. The minimum and maximum principal stresses within the curtain area of splitting grouted are both dominated by tensile stresses. (2) The seriflux seepage reaches into the interior of the dam body, increasing the effective stress inside the soil body which in turn squeezed the soil body to produce counteraction at the seriflux. (3) Additional stress of the grouting axis is remarkable enhanced, thus improving the stress state of the dam body.

3.3. Strain analysis

The vertical and horizontal displacement of earth dam after splitting grouted is shown in figure 4. It is obtained that (1) the maximum vertical displacement is located at the inter-space between grouted area with not-grouted area and the value is 0.014m, which is because of interaction between slurry and soil. The stresses of earth dam are improved effectively. However, some cracks are generated at the dam abutment. (2) Because of the interaction between slurry and soil, the horizontal displacement is generated. The horizontal displacement is increasing as the axis of grouted as the axis and with the increase of distance to the earth axis.



(a) vertical displacement (b) horizontal displacement

Fig.4. Vertical and horizontal displacement of earth dam after splitting grouting

4. Conclusion

Based on the large-scale finite element software ABAQUS and the liquid-solid coupling analysis, the mechanism of interaction between slurry and soil in the earth dam during splitting grouted is investigated effectively. Through the fluid-solid coupling computation, It is obtained that (1) the slurry by splitting grouted is distributing as earth dam axis as the center and diffusing around. (2) The stress of earth dam is improved by the quadratic stress regulation. (3) Because of the interaction between slurry and soil, the horizontal displacement of earth dam by splitting grouted is generated. Those cause the cracks at the dam abutment.

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